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Interaction of Fast Atoms and Ions
With Metal Surfaces

September 1953

Introduction:

Since the last report on this project, work has continued along the three lines outlined then. These are (1) the angular distribution of the electrons emitted by ion and neutral atom bombardment of a metal surface; (2) the velocity distribution of the electrons for these two cases; (3) the reflection of ions and metastables at glancing angles of ion incidence on a metal surface. The progress along each line is discussed below.

I. Angular distribution of emitted electrons

Oliphant and others[1] have suggested that the mechanism by which electrons are removed by fast neutral atoms is a highly localized thermionic emission. That sufficiently high temperatures over a region of several atomic diameters will result from particle bombardment has been shown by calculations of V. Hippel[2] and Townes[3] in discussing cathode sputtering. Measurements of the energy distribution of the electrons often has been found to be exponential with a characteristic Maxwellian temperature of 30,000° - 50,000°K. If such highly localized thermionic emission is the source, then a cosine angular distribution would be expected.

A second mechanism that is suggested by the work done so far on this project is that the neutral atom in the collision with the surface atoms may be ionized. If so, then neutralization will occur in the same way as it does for an impinging ion. Several processes for this have been examined (1) resonance capture and de-excitation by Massey[4], and Cobas and Lamb[5], (2) capture into the ground state with the energy given to a second (emitted) electron by Schekhter.[6] The second "Auger" neutralization seems to be favored by Hagstrum's work[7]. No calculations have been made of the expected angular distribution for any of these mechanisms. However, if the neutral removes an electron by such a process, we would not expect any marked difference in the angular distributions or, in fact, in any other characteristics of emitted electrons for neutral and ion bombardment except the number of electrons. For a clean surface the neutral always has a lower efficiency $\sim$ 1/5 - 1/10 of the ion at several hundred or a thousand electron volts.

With this in mind the angular distributions of electrons removed by 1000 ev. He^+ and He^0 on W were compared. The apparatus is pictured in figure 1. The beam is incident at 30° on a 1 mil tungsten strip 1/8" x 1/4". The collector opening is .05 x 1.0 cm. incidence; in figure 2, this position is given in mm from the normal position.

For comparison, the expected current reduced to one at the normal position has been calculated for an isotropic and a cosine distribution. For this, the source of electrons was assumed to be a point and the calculations represent the (a) integral of the solid angle over the collector slit (b) the integral of the solid angle times the cosine of the angle with the normal over the collector slit. These curves are shown in figure 2. Measurements were made of the angular distribution of the electrons for He^0 on a hot target (about 1000°C.) and for both He^+ and He^0 on a cold (gas covered) target. In the hot target case a small voltage drop ($\sim$ .1 volts) existed along the target and contact potential ($\sim$ .2V) was present in both measurements. Consequently, these preliminary results are not sufficient to decide on a distribution but do serve to show the like character for neutrals and ions.

In future measurements, a half cycle heating and alternate half cycle measurement will be used together with a bias on the target to remove these sources of error.

II. Velocity distribution of emitted electrons.

The apparatus is so designed that the normal velocity distribution and a tangential component distribution may be measured separately. The parallel plane geometry used with a retarding field is the customary technic for the measurement of the normal component distribution. So far measurements of this have not been sufficiently accurate because of electrons removed from the collector plane by the incoming beam and by reflected particles. Several modifications in the apparatus are being made to correct this.

If an electron accelerating voltage is applied between the plates that is large compared with the initial energies associated with the normal component, a measurement of a tangential component distribution is possible. For, if we let $f(V_x)\, f(V_y)\, f(V_z)$ = the volume velocity distribution of the electrons such that the flux distribution with the normal to the surface along z, is $V_z\, f(V_x)\, f(V_y)\, f(V_z)$, then the current to the collector is proportional to

$$\int_0^{\infty} V_z\, f(V_z) dV_z \int_{V_y'}^{V_y''} f(V_y) dV_y \int_{V_x'}^{V_x''} f(V_x) dV_x .$$

Here V_x' = the initial x-component velocity necessary to just reach the inner edge of the collector slit

$$= \frac{1}{z}\, V_z \left(\frac{x - \frac{\delta}{2}}{z} \right) \left(1 + \left(1 + \frac{Ve}{1/2 m V_z{}^2} \right)^{1/2} \right)$$

V = applied potential difference

δ = width of slit along x

V_x'' = the initial x-component velocity to reach the outer edge of the slit. = an expression similar to above.

V_y' and V_y'' are like expressions corresponding to the top and bottom of the slit.

If $\frac{Ve}{1/2 m V_z^2} \gg 1$, the above expression induces to one in which V_z does not appear in the limits. Thus the first two integrals are definite and not a function of x. Only the third is a function of x and approximating the integral over the narrow slit by a differential expression, we have that the current to the collector at any position x is proportional to

$$f \left\{ V_x = \frac{x}{z} \left(\frac{2eV}{mz^2} \right)^{1/2} \right\} \sqrt{\frac{eV}{2mz^2}} \; \Delta x$$

Figure 3 shows the collector current as a function of x for 1000 ev He^0 and He^+ on hot tungsten. The ordinate is the ratio of current at any position to the current at x = 1 mm. (The 1 mm position was chosen as the base because of a beam fluctuation which occurred during the zero reading). The lower abscissa scale represents the x-component velocity in square root of electron volts corresponding to the collector position.

Again here it seems that there is little difference between the electrons removed by neutrals and ions. Perhaps this indicates a like mechanism for the two sources. It may be that the long, high energy tail on the curve is spurious. It is possible that neutrals may be twice reflected and still have enough energy to remove electrons from the target plane. Such electrons would be accelerated across the gap to appear as a current at large x. A mesh target plane will be tried to remove this difficulty.

Signed

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III. The reflection of ions and metastables from nickel surface at glancing angles.

It was desired to investigate the effect of beam incidence angle and hence the effect of particle velocity normal to the reflecting surface on the reflection of the positive ion beam. This experiment was conducted to obtain this information.

The method employed involved only an ion gun, a target and a collector. The angle of incidence of beam on target was variable from 0° to 90° and the collector-target angle was sufficiently adjustable to include all angles of interest. The reflected particles were measured at the collector. The application of a small biasing voltage minimized electron emission from the collector. By a combination of large (grazing) angles of incidence and low accelerating voltages, it was hoped that small normal velocities to the target surface for the incoming positive ions could be obtained.

The apparatus itself is substantially as shown in figure 2 of the January, 1953 report. The ion gun assembly was constructed to give a beam of positive ions, focused at the target surface and with a rectangular cross-section of about 1/16" x 1/4". This incident beam was about 10^{-10} ampere in magnitude. The energy of the beam was continuously variable from zero upwards. Accelerating voltage for the preliminary experiments was 200v.

The target consisted of a strip of 3 mil nickel ribbon, 1/8" x 1/2", mounted so that the target strip could be rotated about an axis perpendicular to the beam axis and in the beam plane. The target was operated at a temperature of about 850 $^{\circ}$C.

The collector assembly consisted of a Faraday cage arrangement with an outer, grounded shield, an intermediate chamber and an inner collector strip. The apertures were arranged to allow only incoming particles from the target surface to strike the collector strip. By a suitable negative potential on the intermediate chamber, electron emission from the collector strip could be minimized when measuring reflected positive ion current. The potential was reversed when it was desired to get an indication of the combined positive ion and metastable reflected currents.

Tentative conclusions which may be drawn from the results so far are: (1) the number of ions reflected at a grazing angle $\sim 5^{\circ}$ was not measurable and if there are any reflected ions they are less than 1 % of the incident beam, (2) the number of metastables produced under these circumstances was also undetectable and assuming one electron removed by each would be less than 1 % of the beam.

Robert Abbott

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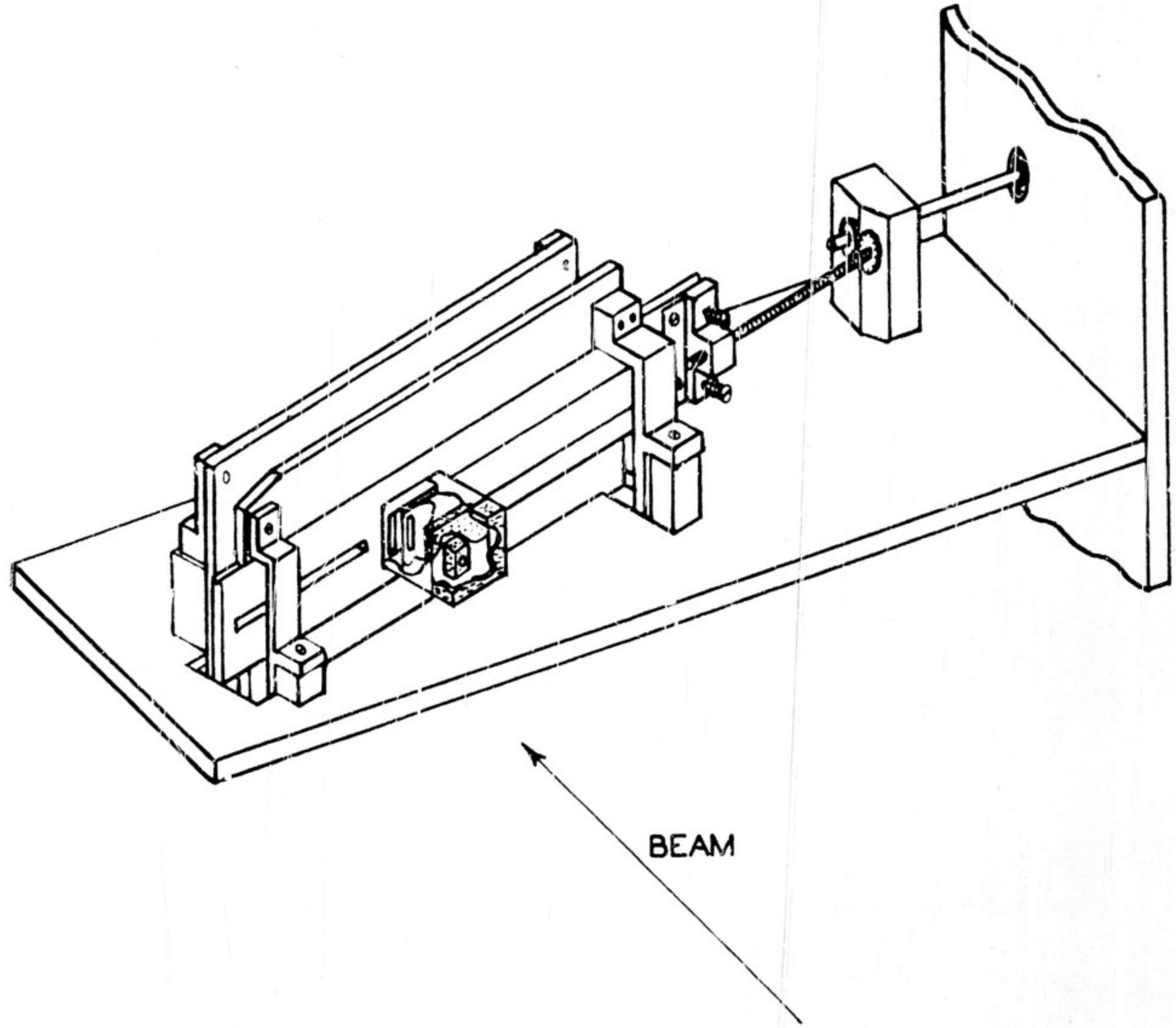
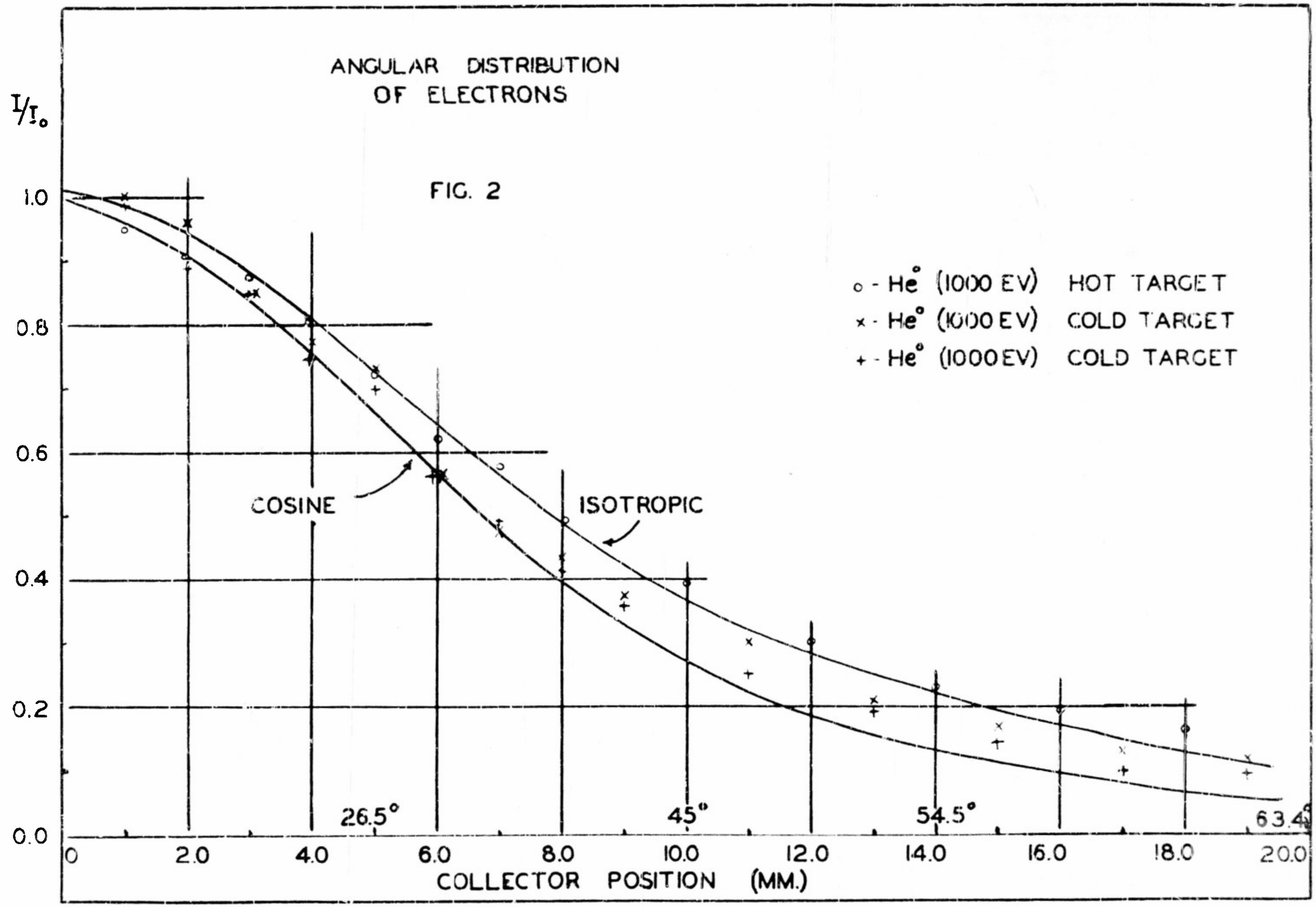


ANALYZER FIGURE 1

ANGULAR DISTRIBUTION OF ELECTRONS

FIG. 2



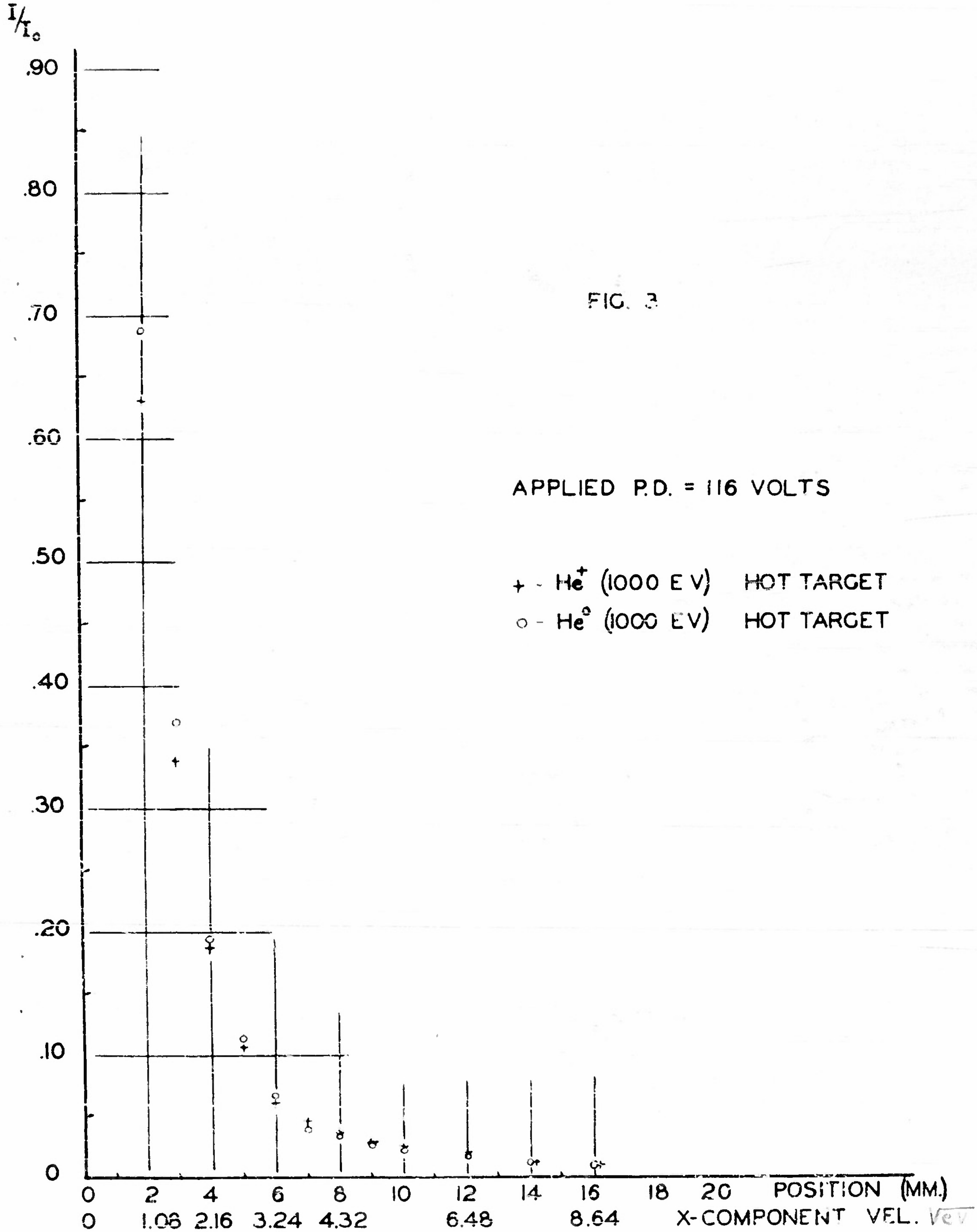


FIG. 3
APPLIED P.D. = 116 VOLTS
+ - He^+ (1000 EV) HOT TARGET
○ - He^0 (1000 EV) HOT TARGET
I/I_0
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
0 2 4 6 8 10 12 14 16 18 20 POSITION (MM.)
0 1.08 2.16 3.24 4.32 6.48 8.64 X-COMPONENT VEL. $\sqrt{eV}$